The grinding energy as an indicator of wheat milling value

Dariusz Dziki[a*], Grażyna Cacak-Pietrzak[b], Beata Biernacka[c], Krzysztof Jończyk[d], Renata Różyło[e], Bożena Gładyszewska[f]

[a]Department of Thermal Technology, University of Life Sciences, Doświadczalna 44, 20-280 Lublin, Poland; [b]Division of Cereal Technology, Faculty of Food Sciences, Warsaw University of Life Science, Nowoursynowska 159C, 02-786 Warsaw, Poland; [d]Department of Systems and Economics of Crop Production, Institute of Soil Science and Plant Cultivation, Czartoryskich 8, 24-100 Puławy, Poland; [e]Department of Equipment Operation and Maintenance in the Food Industry, Doświadczalna 44, 20-280 Lublin, Poland; [f] Department of Physics, University of Life Sciences, Akademicka 13, 20-950 Lublin, Poland

Summary. The aim of the work was to evaluate the relationships between the specific grinding energy and the milling results. The investigations were carried out on nineteen European wheat cultivars (*Triticum aestivum,* ssp. *vulgare*). The grain came from the field experiment conducted in 2010 at Osiny Experimental Station belonging to the Institute of Soil Science and Plant Cultivation located in Puławy. The conditioned kernels were then milled using a Buhler MLU 202 laboratory mill (Bühler AG, Uzwil, Switzerland) and SK labolatory mill. The specific grinding energy ranged from 17.0 $kJkg^{-1}$ (Kobra Plus and Legenda) to 29,9 $kJkg^{-1}$ (cv. Parabola). The results showed statistically significant and negative correlation between the specific grinding energy and break flour yield (r = -0,761). Also the negative correlation was shown between the grinding energy and the total flour yield (r=-0,625). Furthermore, the positive and significant correlation was found between the reduction bran yield and the specific grinding energy (r=0,641). The results showed that specific grinding energy is a useful tool for milling results prediction.

Key words: wheat, milling, grinding energy, flour.

INTRODUCTION

Wheat has become one of the most important crops mainly due to its wheat grain used to flour production. Wheat milling is the most important unit process in wheat processing. The milling methods and milling parameters depend on the direction of wheat use. The most common way of wheat kernel size reduction is a gradual reduction process during the wheat flour milling. This breaks down the tempered wheat grain in a series of grinding stages. Each grinding stage produces a blend of coarse, medium and fine fractions including flour. These mixtures are then sieved and purified to allow for a good separation of bran and endosperm. Adding moisture to wheat prior to milling facilitates breakage of endosperm while making bran more resistant to breakage [7]. The flour obtained in this way consists mainly of the starchy endosperm, whereas bran with the aleurone layer and germs are by-products [18]. While almost any wheat can be milled, millers produce a wide range of flours with can be used to produce variety of products that have good sensory properties. The different types of grinding mills can be used to this end. However, the most commonly applied in practice are the roller mills [19].

The grinding performance depends on the size reduction method and the properties of raw materials. Several studies have addressed the prediction of wheat milling value on the basis of physical properties of wheat grain. Among all the properties of wheat kernel, its hardness has the most significant influence on the milling process [5]. Grain hardness is a key variety trait for milling. Hard and soft wheat has different processing requirements and end-uses. Wheat hardness results mainly from the degree of adhesion between starch granules and the surrounding protein matrix [10]. This property affects the tempering requirements, flour particle size, flour density, starch damage, water absorption, and milling yield [12,21]. Also other properties of wheat are commonly determined, including: test weight, vitreousness, true density, kernel size and weight, and protein content [15,3,8].

The grinding energy depends mainly on wheat mechanical properties. Thus the grinding energy can be an indirect indicator of wheat mechanical properties and correlated strongly with grain hardness [6,4]. The objective of this study was to investigate the relationships between specific grinding energy and wheat milling results.

MATERIALS AND METHODS

MATERIAL

Investigations were carried out on nineteen European wheat cultivars (*Triticum aestivum, ssp. vulgare*):

Bogatka, Bombona, Bryza, Cytra, Figura, Kobra Plus, Legenda, Nawra, Ostka Strzelecka, Parabola, Raweta, Rywalka, Smuga, Tonacja, Tybalt, Vinjet, Wydma, Zadra, Żura. The grain came from the organic field experiment conducted in 2010 at Osiny Experimental Station belonging to the Institute of Soil Science and Plant Cultivation (State Research Institute) located in Puławy. The grain initial moisture content of kernel ranged form 8.5 to 9.8% (w.b.). The samples of wheat were prepared by adding water to adjust moisture content to 14% (w.b.) and storing for 48 h.

THE GRINDING ENERGY EVALUATION

The samples (50 g) were milled using SK laboratory roller mill. Four grinding stages were applied. The roll gap was 0.85 mm for the first stage, 0.4 mm for the second stage, 0.25 mm for the third stage and 0.15 mm for the fourth stage.

The changes in the power consumption of the electric current during the grinding process were recorded using laboratory equipment including a grinding machine, transducer of power and a special data acquisition card connected to a PC computer and operated with special computer software. The detailed description of the laboratory mill has been provided by Dziki et al [3].

The total grinding energy (E_c) was calculated according to the equation:

$$E_c = \int_0^t P dt, \quad (1)$$

where:

P – the power consumption during grinding process (W),

t – the time of grinding (s).

It was assumed that the power consumption during the kernel grinding process is the difference between the total grinding power and the power of transmission system during the idle running. The idle running energy lose was calculated as follow:

$$E_s = \int_0^t P_j dt, \quad (2)$$

where:

P_j – the power consumption during idle running (W).

The specific grinding energy was calculated according to the formula:

$$E_r = \frac{E_c - E_s}{m}, \quad (3)$$

where:

m – the mass of the grinding sample (kg).

The specific grinding energy was carried out in ten repetitions.

THE MILLING PROCESS

Three kilograms of cleaned wheat kernel from each cultivar were conditioned in two steps. First, water was added to increase the moisture content of wheat kernel to 13.5% (w.b.) moisture level 24 h before milling. Then, kernel moisture was increased to 14% (w.b.) followed by 30 min tempering. The conditioned kernels were then milled using a Buhler MLU 202 Laboratory Mill (Bühler AG, Uzwil, Switzerland). The gap settings and the size of screens used in the mill are presented in Table 1. The break flour and the reduction flour were obtained by blending the flours from the breaking and reduction stages, respectively. The total flour was obtained by blending break flour with the reduction flour. The individual flour yields were expressed as the percentage in weight of ground grains. The content of total ash was determined [13] and the index of milling efficiency was calculated as a ratio of the total flour yield to flour ash content [1,2]. The milling process and the determination of the total ash content were carried out in triplicate.

Table 1. The roll gaps settings and size of screens used in the mill.

Stage	Roll gap (mm)	Size of screen (mm)
S_I*	0.52	0.244
S_{II}	0.10	0.180
S_{III}	0.07	0.150
W_1	0.05	0.225
W_2	0.01	0.180
W_3	0.01	0.150

*S_I, S_{II}, S_{III} – the first, the second and the third breaking stage, respectively,

W_1, W_2, W_3 – the first, the second and the third reduction stage, respectively

STATISTICAL ANALYSIS

Statistical analysis of the data collected in this study were conducted with Statistica 6.0 software (StatSoft Inc., Tulsa, USA). Variance analysis (using Tukey's test) was used to determine statistical differences between treatment groups. Correlation analysis was also carried out on the data. All the statistical tests were carried out at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The results showed that the specific grinding energy ranged form 17.0 $kJkg^{-1}$ (Kobra Plus and Legenda) to 29,9 $kJkg^{-1}$ (cv. Parabola) (Fig. 1). The specific grinding energy is one of the most frequently determined parameters characterizing the grinding process [9,20,14] found that the total specific milling energy ranged from 46 $kJ \cdot kg^{-1}$ for soft wheat cultivars to 124 $kJ \cdot kg^{-1}$ for durum wheat.

The results of wheat milling process were given in tables 2 and 3. The yield of break flour ranged from

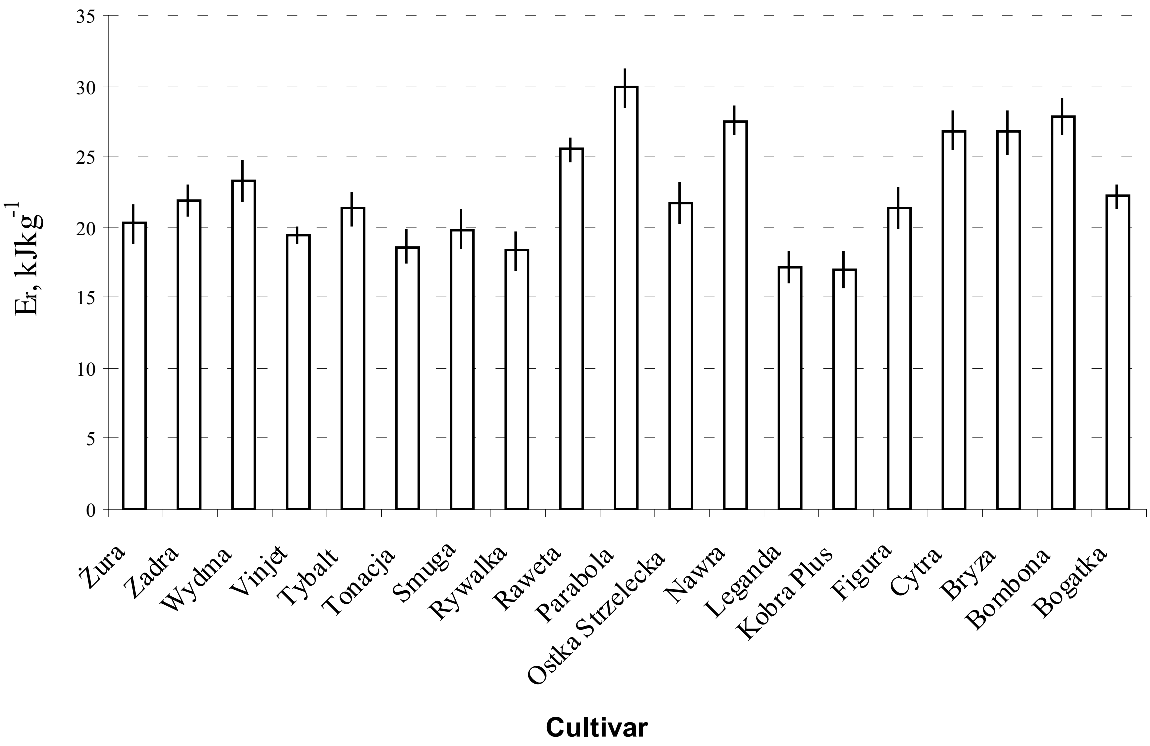

Fig. 1. The results of specific grinding energy of individual wheat cultivars

15.5% (cv. Bombona) to 22.2% (cv. Rywalka). The lowest yield of reduction flour was obtained for Nawra and Żura (53.1% and 53.4%, respectively), and the highest for Bombona (59.1%).

Table 2. The milling results

Cultivar	*BFY** (%)	*RFY* (%)	*BBY* (%)	*RBY* (%)
Bogatka	20.7^{hij**}	55.4^{fg}	12.7^{cd}	11.2^{bcd}
Bombona	15,5^{a}	59.1^{j}	13.2^{cde}	12.2^{defg}
Bryza	19^{cde}	55.7f^{g}	14.8^{ij}	10.5^{b}
Cytra	17.9^{b}	56.0^{gh}	15.1^{j}	11.0^{bc}
Figura	21.2^{j}	54.4^{cde}	11.9^{ab}	12.5^{efg}
Kobra Plus	20.8^{jk}	58.3^{i}	12.5^{bc}	8.4^{a}
Legenda	20.5^{hij}	55.4^{fg}	12^{ab}	12.1^{cdef}
Nawra	19.3^{def}	53.1^{a}	13.8^{fgh}	13.8^{h}
Ostka Strzelecka	19.5^{efg}	54.3^{cde}	12.7^{cd}	13.5^{gh}
Parabola	17.9^{bc}	55.7^{fg}	14^{gh}	12.4^{cdef}
Raweta	18.3^{bc}	54.3^{cd}	14.4^{hi}	13^{fgh}
Rywalka	22.2^{k}	53.6^{ab}	12^{ab}	12.2^{cdef}
Smuga	19.7^{efgh}	55^{def}	13.2^{def}	12.1^{cde}
Tonacja	20.2^{ghi}	56.5^{h}	11.8^{a}	11.5^{bcde}
Tybalt	18.4^{bcd}	55.1^{ef}	13.9^{gh}	12.6^{efg}
Vinjet	20.8^{ij}	54.1^{bc}	14^{gh}	11.1^{bc}
Wydma	19.8^{fghi}	54.6^{cde}	12.9^{cd}	12.7^{efg}
Zadra	19.9^{fghi}	54.4^{cde}	13.6^{efg}	12.1^{cdef}
Żura	20.4^{hij}	53.4^{ab}	14^{gh}	12.2^{cdef}

**BFY* – break flour yield, *RFY* – reduction flour yield, *BBY* – break bran yield, *RBY* – reduction bran yield, **the values designated by the different letters in the columns of the table are significantly different (α = 0.05);

The total flour extraction ranged from 72.4% to 79.1% for Navra and Kobra Plus, respectively (Table 3). Flour extraction depends mainly on both the kernel properties and the manner of milling. However, during production of white flour apart from yield also the flour ash content has a significance for milling results. Since ash is primarily concentrated in the bran, ash content of flour is an indicator of the yield and purity of the flour. In many countries wheat flour is classified according to the ash content. One of the best indicators of wheat milling value is a milling efficiency index (*MEI*), which is defined as a ratio of total flour yield to flour ash content, the higher value of this index the better the milling value of wheat [1]. The results showed that the *MEI* ranged from 100.3 (cv. Bryza) to 118.5 (cv. Tybalt).

Table 3. Total flour yield, flour ash content and milling index for the investigated wheat cultivars

Cultivar	*TFY** (%)	*FAC* (%)	*MEI*
Bogatka	76.1^{ef**}	0.681^{efg}	111.1^{cdef}
Bombona	74.6^{cde}	0.639^{bcd}	116.6^{ef}
Bryza	74.7^{cde}	0.745^{i}	100.3^{a}
Cytra	73.9^{bc}	0.721^{hi}	102.6^{ab}
Figura	75.6^{def}	0.695^{fgh}	108.8^{bcd}
Kobra Plus	79.1^{g}	0.702^{fgh}	113.0^{cdef}
Legenda	75.9^{ef}	0.660^{cde}	115.0^{def}
Nawra	72.4^{a}	0.635^{bc}	114.0^{cdef}
Ostka Strzelecka	73.8^{abc}	0.632^{abc}	117.1^{ef}
Parabola	73.6^{bc}	0.671^{def}	109.9^{cde}
Raweta	72.6^{ab}	0.705^{gh}	103.0^{ab}
Rywalka	75.8^{def}	0.655^{cde}	115.7^{def}
Smuga	74.7^{cde}	0.601^{a}	124.5^{g}
Tonacja	76.7^{f}	0.675^{efg}	113.6^{cdef}
Tybalt	73.5^{abc}	0.621^{ab}	118.5^{fg}
Vinjet	74.9^{cde}	0.695^{fgh}	107.8^{bc}
Wydma	74.4^{cde}	0.672^{def}	111.0^{cde}
Zadra	74.3^{cd}	0.670^{def}	110.9^{cde}
Żura	73.8^{abc}	0.671^{def}	113.5^{cde}

**TFY* – total flour yield, *FAC* –flour ash content, *MEI* – milling efficiency index, **the values designated by the different letters in the columns of the table are significantly different (α = 0.05);

The results showed significant correlation between the specific grinding energy and break flour yield (Fig. 2). As the grinding energy increased the break flour yield decreased (r = 0,761). Also, the negative correlation was found between specific grinding energy and total flour yield (r= -0,625) (Fig. 3). Literature data showed that during milling, the wheat hardness significantly affected the break flour yield and the total flour yield [16,10,17]. The soft wheat kernels are characterized by a higher break flour, because degree of adhesion between starch granules and protein matrix is week and thus the higher mass fraction of fine particles is produced [11,21].

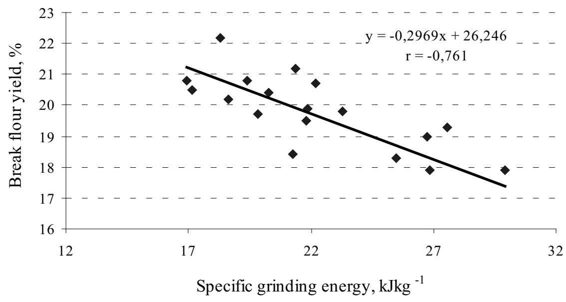

Fig. 2. The relationship between specific grinding energy and break flour yield

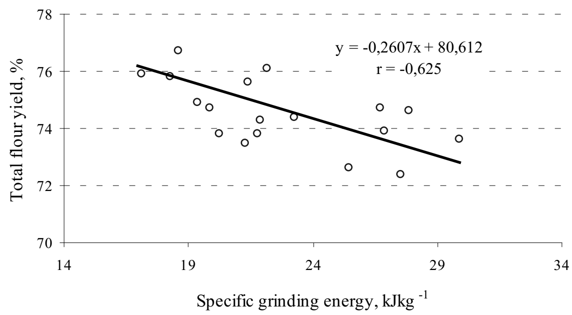

Fig. 3. Relationship between specific grinding energy and the total flour yield

The positive and significant correlation was also found between the reduction bran flour yield and the specific grinding energy (Fig. 4). The coefficient of correlation was significant, but relatively low (r= 0,641).

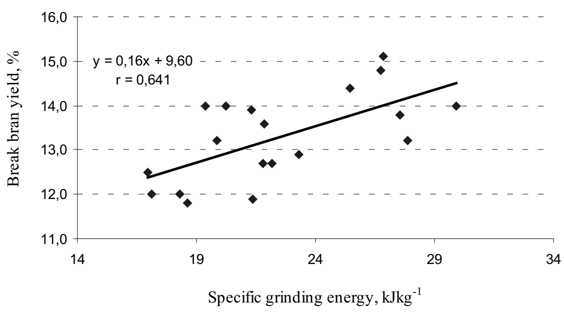

Fig. 4. The relationship between specific grinding energy and bran yield reduction

CONCLUSIONS

On the basis of the obtained investigation results the following conclusions were formulated:

1. The specific grinding energy ranged from 17.0 $kJkg^{-1}$ (Kobra Plus and Legenda) to 29,9 $kJkg^{-1}$ (cv. Parabola).

2. The results showed statistically significant and negative correlation between the specific grinding energy and: break flour yield (r = -0,761), and total flour yield (r = -0,625).

3. The positive correlation was found between grinding energy and reduction bran yield (r= -0,641).

4. The results showed that specific grinding energy is a useful tool for predicting flour yield.

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ENERGOCHŁONNOŚĆ ROZDRABNIANIA JAKO WSKAŹNIK WARTOŚCI PRZEMIAŁOWEJ ZIARNA PSZENICY

Streszczenie. Celem pracy było określenie zależności między energochłonnością jednostkową rozdrabniania a wynikiem procesu przemiału ziarna pszenicy. Materiał badawczy stanowiło 19 europejskich odmian pszenicy zwyczajnej (*Triticum aestivum,* ssp. *vulgare*). Ziarno pochodziło ze zbiorów z 2010 roku, ze Stacji Eksperymentalnej w Osinach, należącej do Instytutu Uprawy, Nawożenia i Gleboznastwa w Puławach. Ziarno kondycjonowano do 14% wilgotności i poddawano przemiałowi laboratoryjnemu, wykorzystując młyn Buhler MLU 202 oraz mlewnik walcowy typu SK. Stwierdzono, że energochłonność jednostkowa rozdrabniania kształtowała się od 17.0 $kJkg^{-1}$ (odmiany Kobra Plus i Legenda) do 29,9 $kJkg^{-1}$ (odmiana Parabola). Parametr ten istotnie i ujemnie korelował z wyciągiem mąki śrutowej (r=-0,761) oraz z całkowitym wyciągiem mąki (r=-0,625). Ponadto wykazano występowanie dodatniej korelacji między energochłonnością jednostkową rozdrabniania a wydajnością odtrąb śrutowych (r=0,641). Przeprowadzone badania wykazały, że energochłonność jednostkowa rozdrabniania może być użytecznym narzędziem w prognozowaniu wartości przemiałowej pszenicy.

Słowa kluczowe: pszenica, przemiał, energia rozdrabniania, mąka.